Argonne NATIONAL LABORATORY

Use of Life Cycle Analysis (LCA) and Life Cycle Costing (LCC) Models in Waste-to-Materials and Energy Pathways

UISUNG LEE - ARGONNE NATIONAL LAB

ALICYN RHOADES + GAMINI MENDIS–
PENN STATE BEHREND, AREC USA

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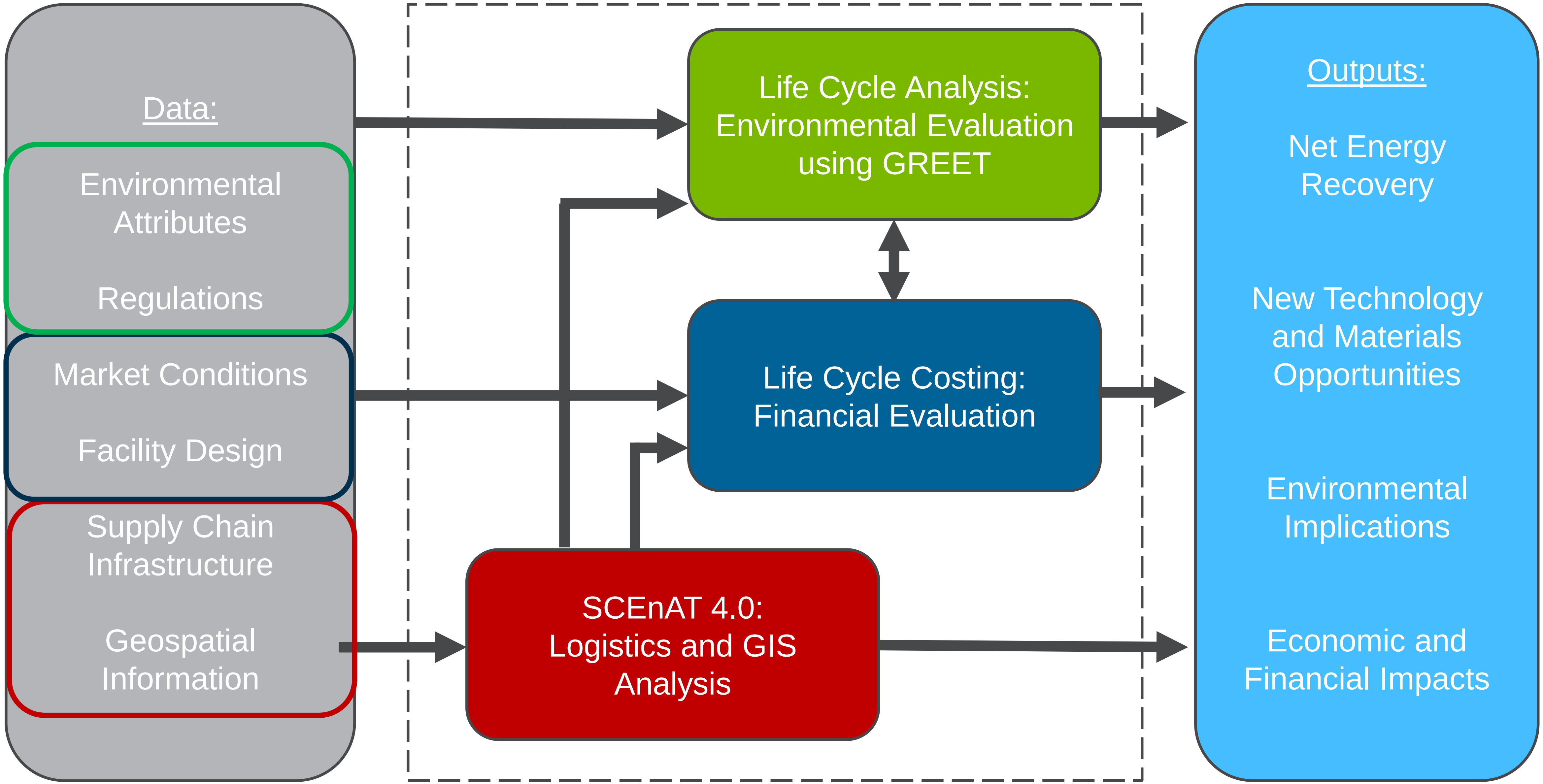
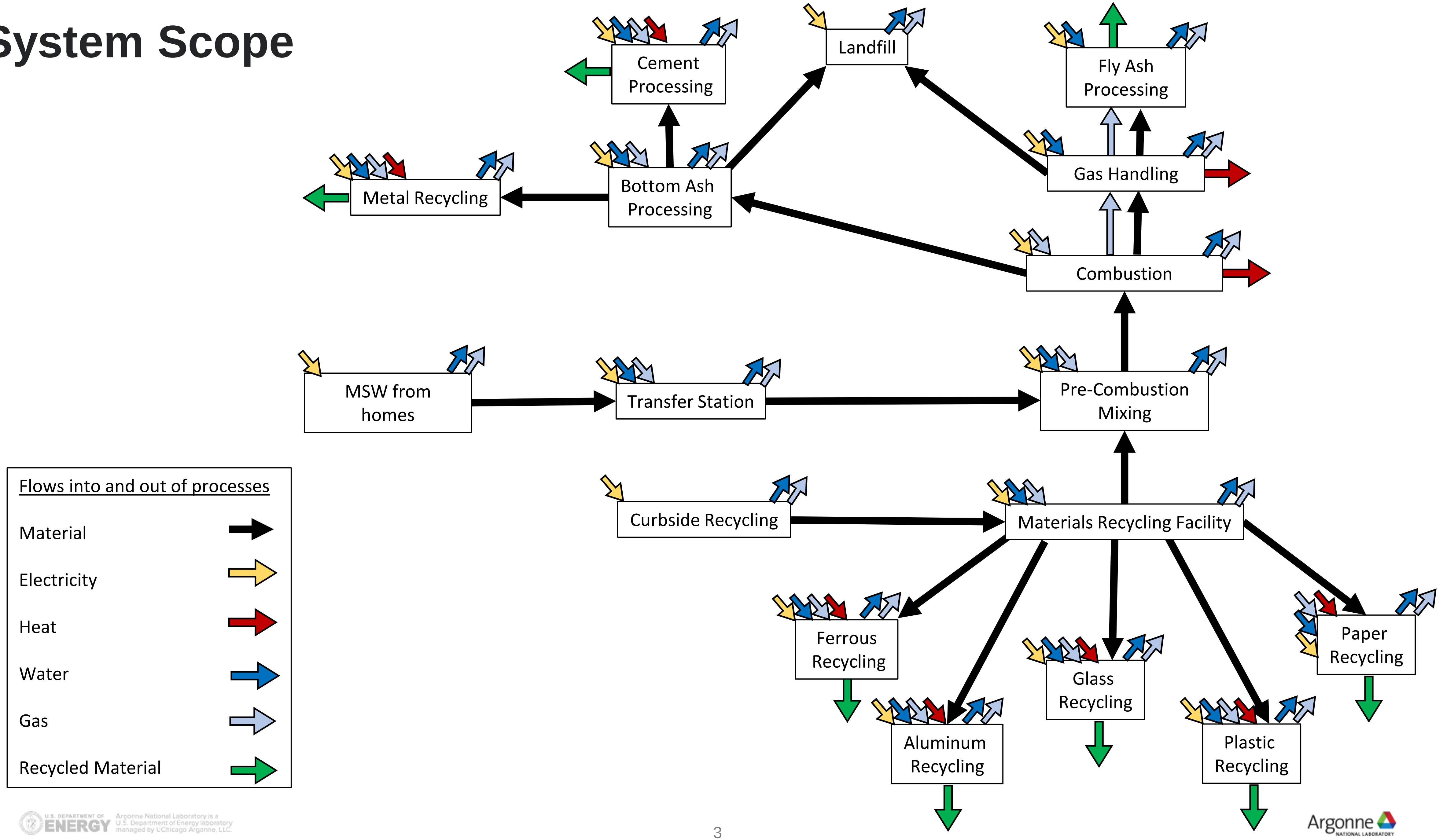
AREC Creating the Supply Chain of the Future.

PennState

Framework Organization



System Scope



Objective: Develop a framework to enable evaluating quantitative environmental and economic benefits of ARPA-E projects

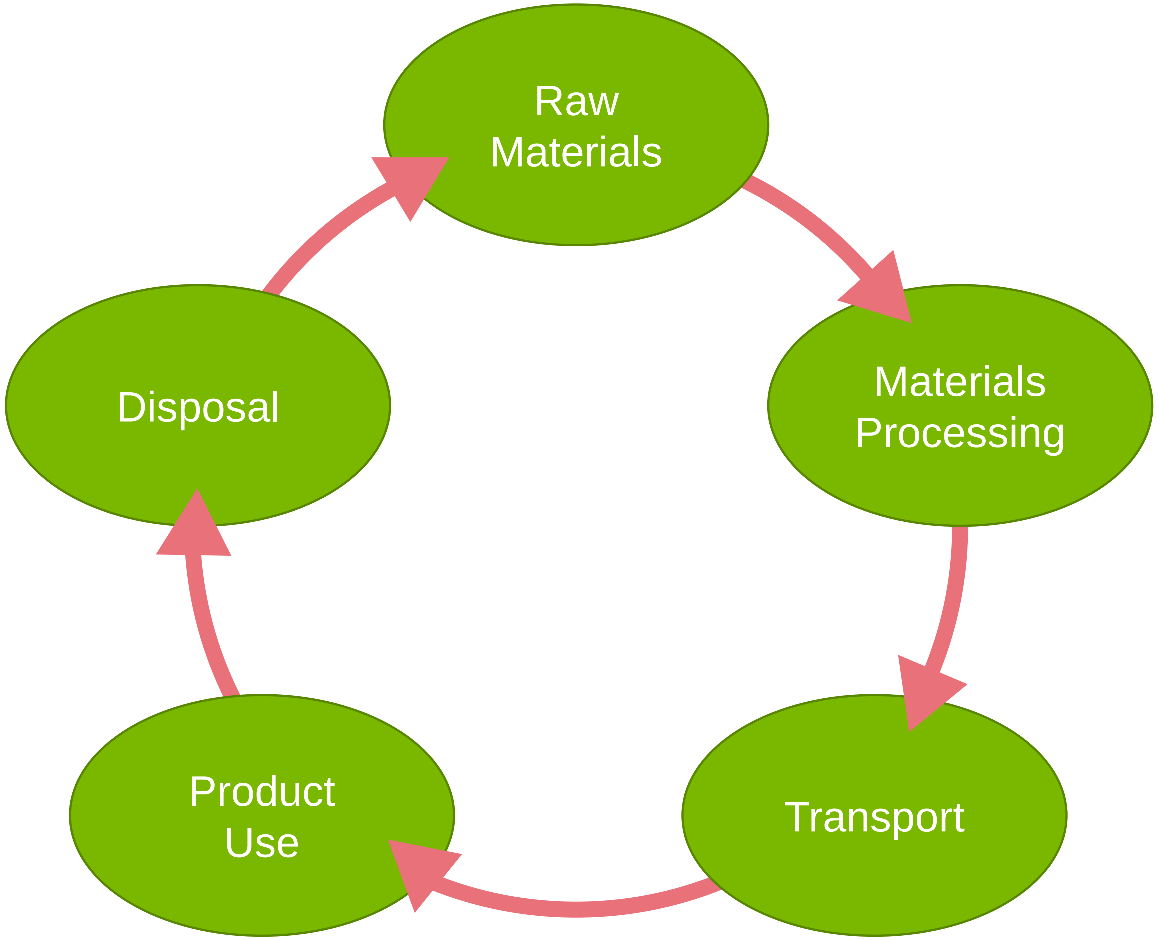
Potential Results

- ❑ **Functional unit**: ton of waste used
- ❑ **LCA results:**
  - Greenhouse gas (GHG) emissions
  - Air pollutant emissions (VOC, CO, NOx, PM10, PM2.5, and SOx)
  - Energy use (fossil energy and renewable energy)
  - Net energy recovery
  - Water consumption
- ❑ **Life Cycle Costing (LCC)**
  - ❑ Return on Investment (ROI), Fixed and Variable Costs

- Can compare the environmental and economic benefits of ARPA-E projects in a consistent manner.
- Can provide quantitative environmental and economic benefits of WTM&E technologies that help improve public perception.

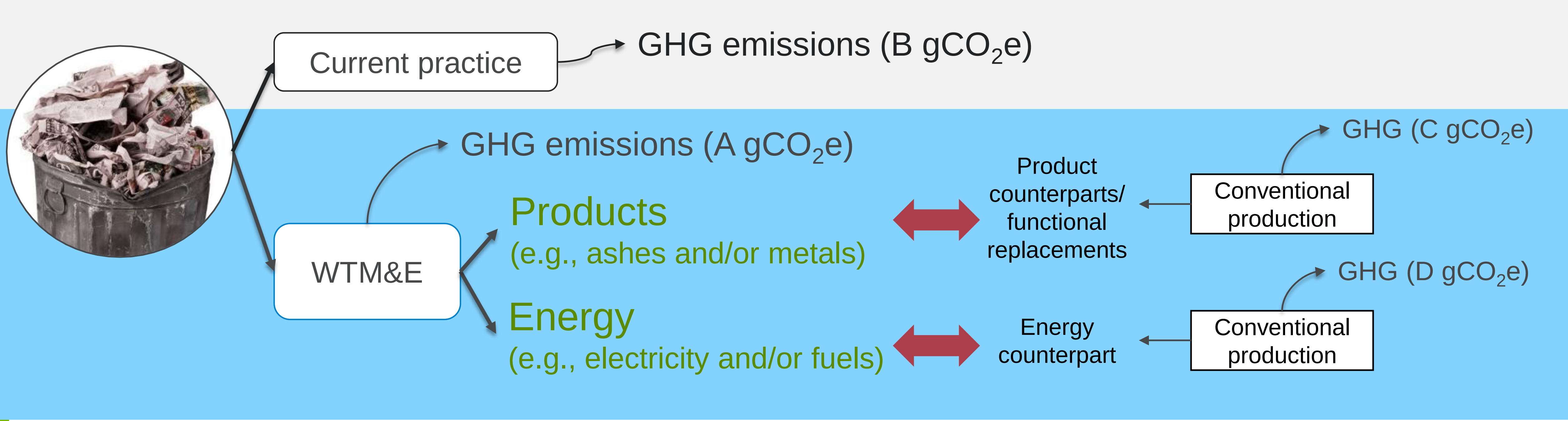
Life Cycle Analysis (LCA)

- Examines environmental impacts (GHG emissions, ozone depletion, etc.) over entire life cycle
- Cradle-to-grave or cradle-to-cradle
- Comparative LCA: Evaluate environmental impacts of multiple systems, i.e. recycling vs landfilling vs combustion
- Total environmental impacts may not be intuitive, i.e. transportation distance for recycling may have high fuel use
- **Identify opportunities to minimize negative environmental impacts of plastics through industry partnerships**



The system boundary of the LCA of WTM&E in the GREET LCA model

- Using waste avoids emissions from conventional waste management practices.
  – Waste is not intentionally produced / Waste management is regulated.

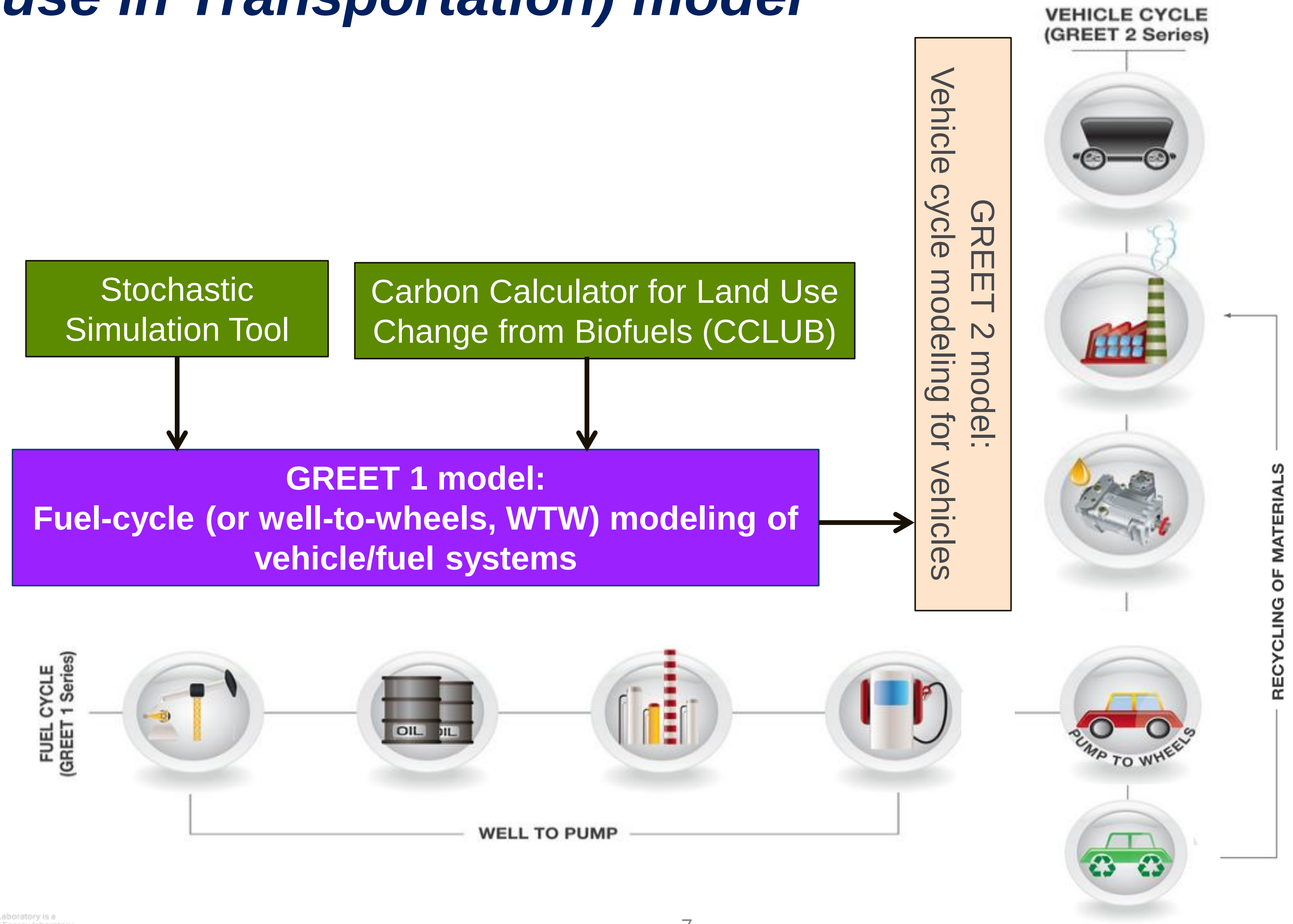


- Waste-To-Materials and Energy (WTM&E) pathway emissions: A gCO_2e.
- By diverting waste, emissions associated with current waste management (B gCO_2e) can be avoided.
- WTM&E products displace counterparts and avoid emissions from conventional products (C and D gCO_2e).

A gCO_2e
\- B gCO_2e
\- C gCO_2e
\- D gCO_2e

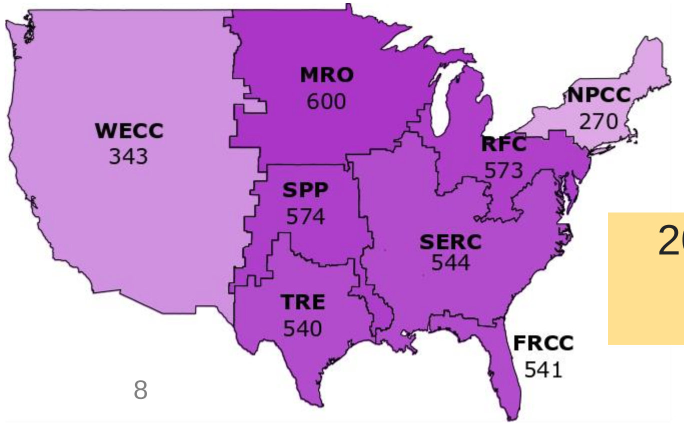
Life Cycle Emissions

The GREET® (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) model



GREET Database

	Aluminum (Virgin)	Cast Iron	Cement	Copper	Glass	LDPE	HDPE	Polypropylene	PVC	Rubber	Silicon	Average Steel	Nickel	Zinc	Magnesium	Platinum
Energy Use (mmBtu/ton)																
Total energy	127	30	4	38	13	74	69	67	50	47	3,169	26	71	37	113	983
Fossil fuels	81	29	4	33	12	72	67	66	48	46	2,301	24	65	30	102	958
Coal	29	21	2	11	3	5	5	4	5	2	952	17	14	14	24	885
Natural gas	37	6	1	15	9	58	54	46	39	26	1,267	7	39	14	77	13
Petroleum	15	2	1	7	0	8	8	16	4	18	83	0	12	1	1	60
Water consumption (gal/ton)	63,528	307	279	3,118	781	1,404	1,384	1,171	1,115	911	688,244	1,285	18,341	6,378	5,354	49,256
Total Emissions (grams/ton)																
VOC	966	2,015	100	327	138	1,357	1,284	1,151	799	5,708	22,219	2,379	747	289	1,069	8,649
CO	2,718	890	1,143	2,303	595	4,997	4,772	7,643	3,053	2,037	77,504	17,139	7,761	930	4,285	14,204
NOx	5,861	1,449	1,246	6,045	1,614	3,392	3,113	2,882	2,935	4,579	154,173	2,162	21,258	1,805	7,152	63,264
PM10	4,791	1,003	213	576	99	311	310	259	234	751	21,887	1,368	7,210	1,929	684	13,863
PM2.5	2,382	458	116	310	66	133	127	105	124	399	10,686	652	3,645	949	418	5,506
SOx	29,307	2,954	379	131,837	1,090	23,729	23,319	21,309	12,057	12,514	315,951	8,412	595,110	3,895	6,944	243,889
BC	49	7	4	85	8	22	19	18	26	38	1,086	10	394	11	67	349
OC	80	18	14	56	16	40	34	31	39	58	2,281	23	159	26	126	632
CH4	12,628	4,234	337	5,131	2,194	25,952	24,854	23,238	14,965	6,995	382,856	3,877	10,846	4,800	18,476	138,024
N2O	114	15	6	48	19	94	85	76	69	82	3,656	22	102	38	167	1,409
CO2	7,085,341	797,544	855,909	2,570,491	1,065,870	2,071,651	1,835,912	1,527,024	1,971,802	3,294,338	177,494,631	2,236,042	4,681,093	2,400,421	7,842,467	94,038,262
GHGs	8,144,349	936,140	869,795	2,741,759	1,138,132	2,887,287	2,615,597	2,260,010	2,446,304	3,546,809	190,140,203	2,392,589	5,047,935	2,556,816	27,710,579	98,601,677

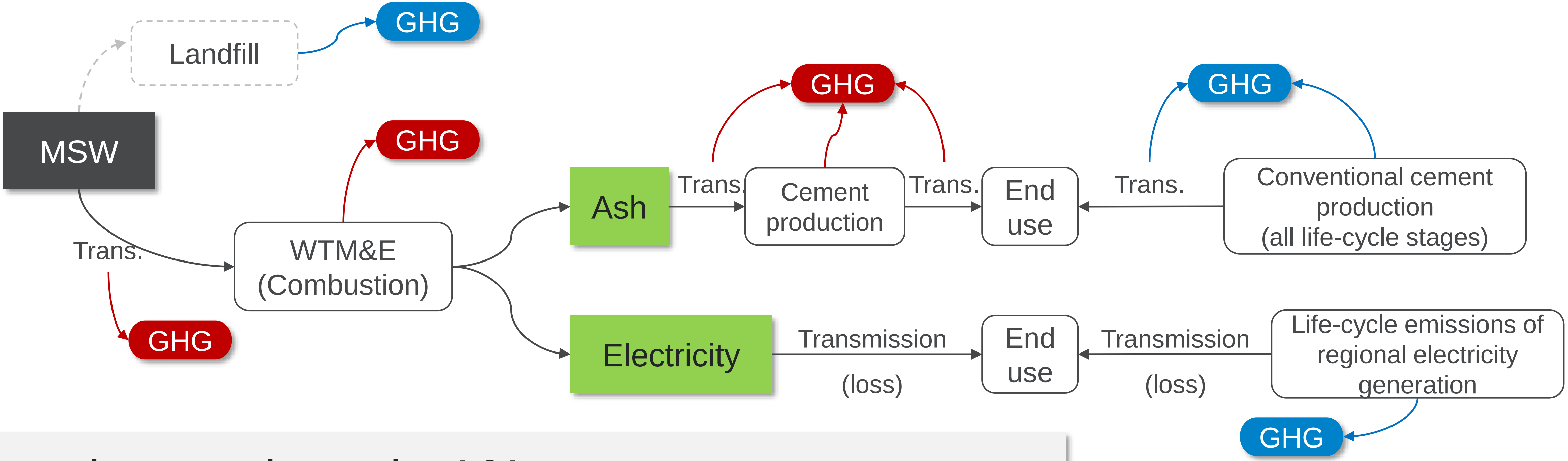


Unit: grams g_CO_{2e}/kWh

2019 U.S. electricity generation mix

483 g_CO_{2e}/kWhe at the plug

The example of the proposed LCA framework system boundary

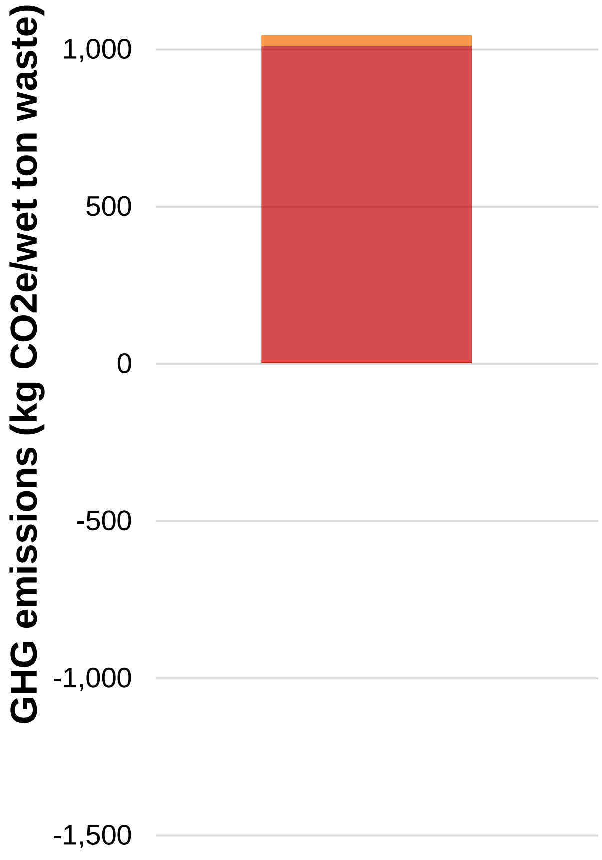


- **Information we need to conduct LCAs:**
  - Waste composition
  - Estimated emissions from current waste management practices
  - Logistics (waste and products) and associated energy use and emissions
  - Inputs/outputs of the WTM&E (material and energy production per unit waste) and additional processes (e.g., cement from ash)
  - Life-cycle results of the corresponding counterparts.

GHG	Avoided GHG emissions (negative)
GHG	Positive GHG emissions

Preliminary results of the case study

	Case 1
Cement production (ton/ton waste)	0.1
Electricity generation (kWh/ton waste)	700



Generating cement and electricity from MSW combustion

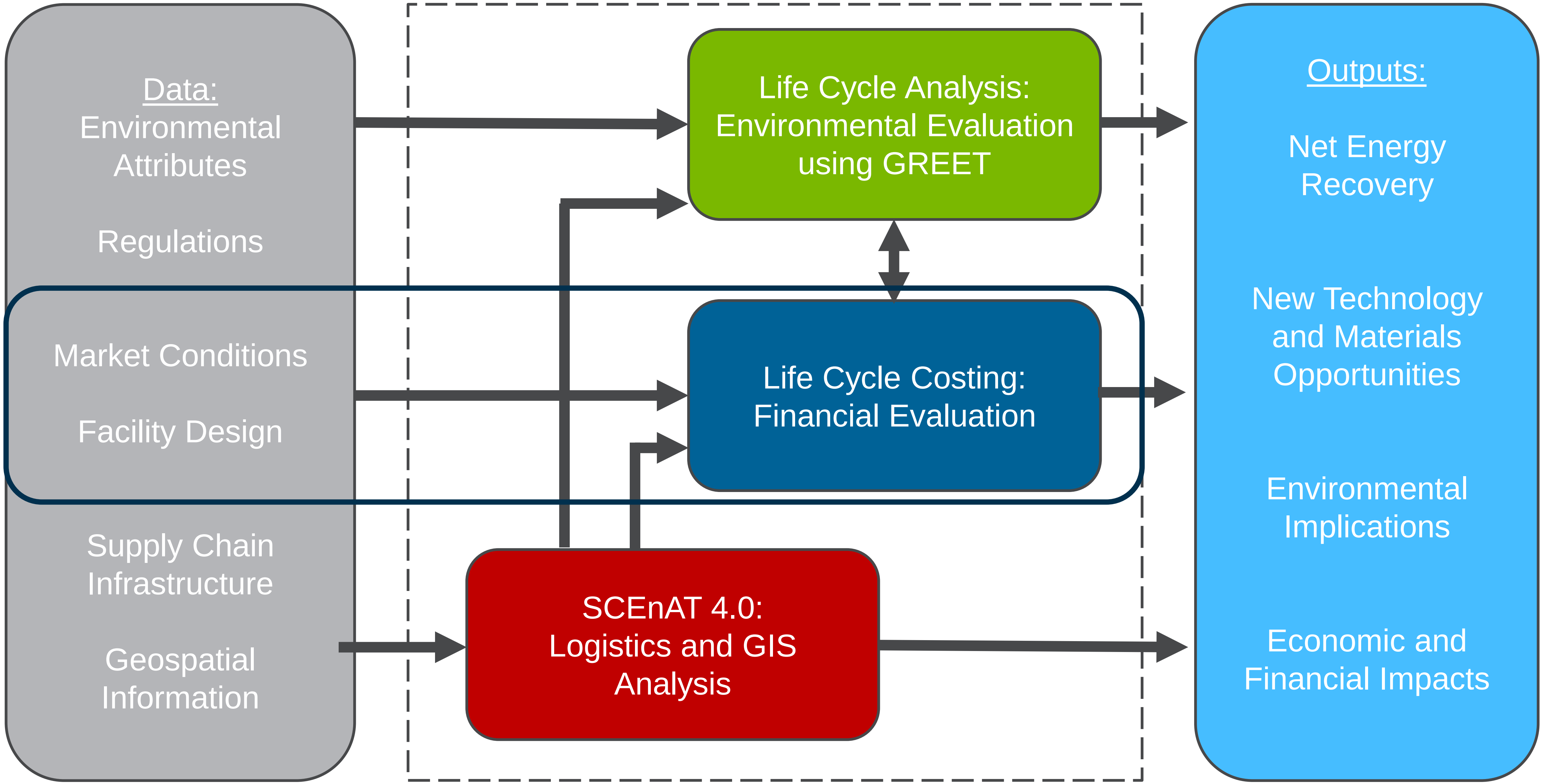
- A - Waste transportation (30 mi)
- A - Emissions from waste incineration
- A - Ash transportation (45mi)

Preliminary results of the case study

	Case 1	Case 2	Case 3
Cement production (ton/ton waste)	0.1	0.2	0.3
Electricity generation (kWh/ton waste)	700	800	900

Generating cement and electricity from MSW combustion

Framework Organization

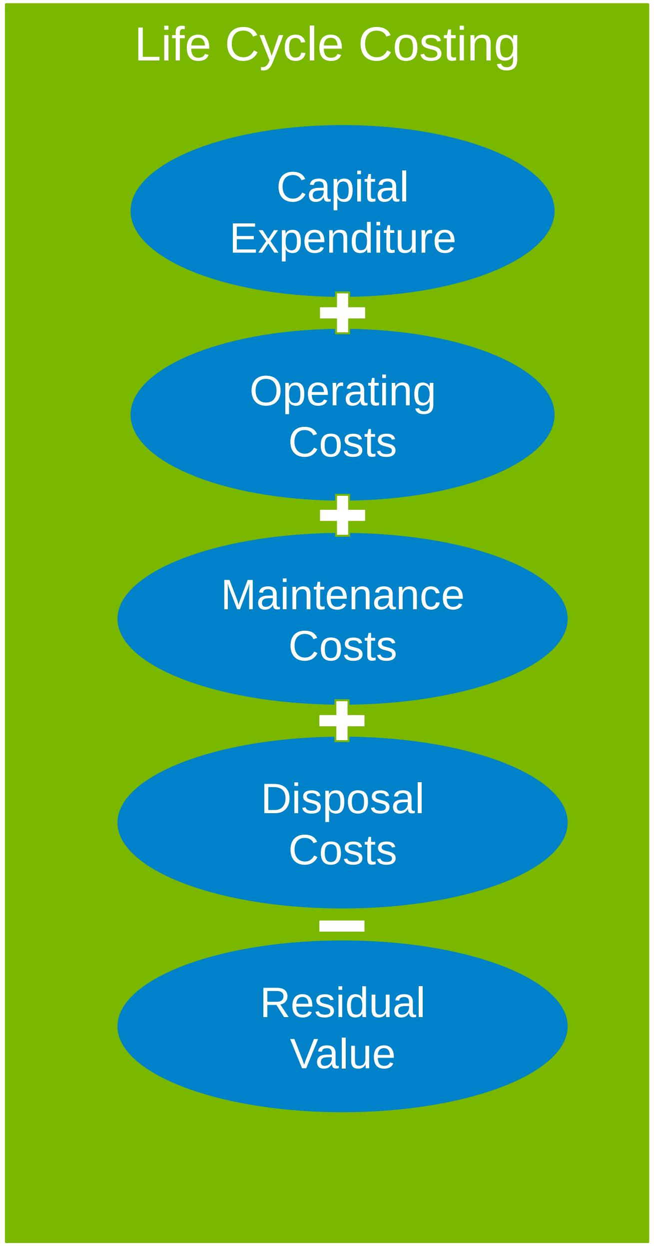


Life Cycle Costing (LCC)

- Similar to LCA, LCC evaluates costs over the lifetime of a system
  - Includes cost of facility creation, useful life of equipment and facilities, maintenance, revenue, etc.

- LCC methods will be informed by the system boundaries determined by the LCA approach

- Develop Life Cycle Costing to act alongside GREET framework
  - Costing models for:
    - Collection
    - Sorting
    - Combustion
    - Landfilling
    - Other End-of-Life processes, as needed
      - Thoughts?



Potential Costs and Revenues from MSW management

Collection

<u>Fixed Costs</u>
- Vehicle fixed costs
  - Purchasing
- Vehicle storage site
  - Construction, etc.

<u>Variable Costs</u>
- Utilities
- Maintenance
- Labor
- Vehicle variable costs
  - Gas
  - Travel distance
  - Maintenance

<u>Revenues</u>
- Collection Fee
- Municipal Subsidy

Recycling

<u>Fixed Costs</u>
- Permitting
- Land cost
- Construction
- Equipment

<u>Variable Costs</u>
- Utilities
- Maintenance
- Labor
- Landfill Tipping Fees

<u>Revenues</u>
- Collection Fee
- Municipal Subsidy
- Sale of Metals, Plastics, Glass, etc.

Combustion

<u>Fixed Costs</u>
- Permitting
- Land cost
- Construction
- Equipment

<u>Variable Costs</u>
- Utilities
- Maintenance
- Labor
- Landfill Tipping Fees

<u>Revenues</u>
- Waste Disposal
- Fly Ash and Bottom Ash
- Metals
- Energy
- Heat

Landfilling

<u>Fixed Costs</u>
- Permitting
- Land cost
- Equipment
- Labor
- Landfill capping

<u>Variable Costs</u>
- Utilities
- Maintenance
- Labor

<u>Revenues</u>
- Tipping/Host Fee
- Gas Sale

Instructions:
Please identify (X) which categories are particularly important for the analysis.
If something is missing, please write it in. If more space is required, or you would like to comment, please use the back of the document.
If you or your company/institution would be willing to partner with us to collect information, please circle the category

Optional
Name:____________________________________
Company:_________________________________
Email:____________________________________

Economic Drivers
What factors drive economic decision making?

- ❑ Price of Produced Materials (Metal, etc.)
- ❑ Fixed Costs/Variable Costs for Facilities
- ❑ Geographic Cost Factors
- ❑ Price of Fuel/Electricity
- ❑ Permitting/Compliance Costs
- ❑
- ❑

Economic Outputs
What economic information would be useful for analysis and decision making?

- ❑ Return on Investment (ROI)
- ❑ Cost Breakdown for Processes in MSW Supply Chain (Collection, Combustion, etc.)
- ❑ Cost Breakdown for Unit Operations
- ❑ Revenue from Sources (Fees, Recycled Materials, Energy Generation, etc.)
- ❑
- ❑
- ❑

Collection

Fixed Costs
Vehicle Fixed Costs
- ❑ Purchasing

Vehicle Storage Site
- ❑ Construction, Permitting, etc.
- ❑

Variable Costs
Vehicle variable costs
- ❑ Gas/Travel Distance
- ❑ Maintenance
- ❑ Insurance
- ❑

Revenues
- ❑ Collection Fee
- ❑ Municipal Subsidies
- ❑
- ❑
- ❑

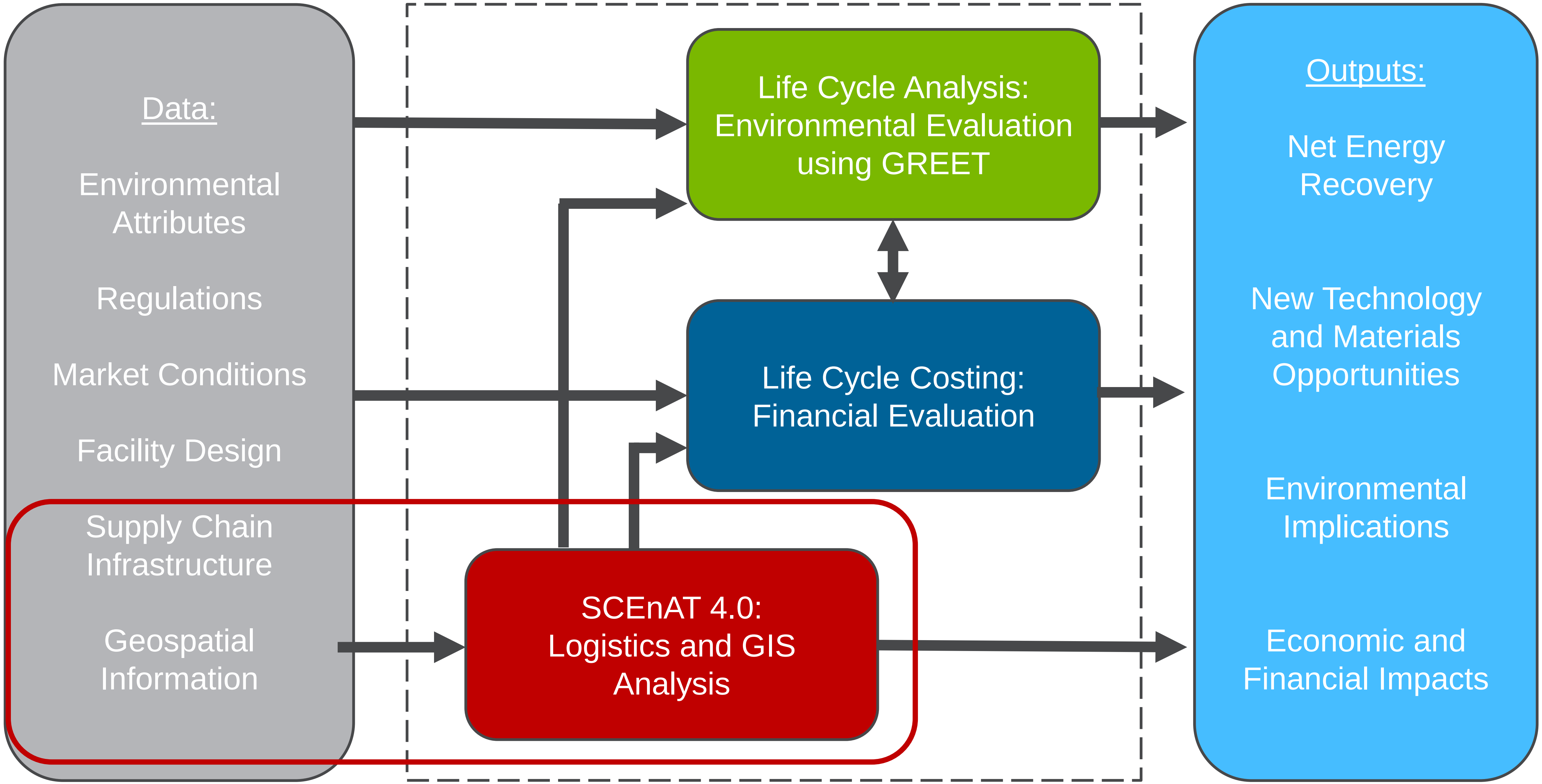
Combustion, Recycling, Landfilling

Fixed Costs
- ❑ Permitting
- ❑ Land cost
- ❑ Construction
- ❑ Equipment
- ❑
- ❑
- ❑
- ❑
- ❑
- ❑
- ❑

Variable Costs
- ❑ Utilities
- ❑ Maintenance
- ❑ Labor
- ❑ Landfill Tipping Fees
- ❑ Wastewater and Gas Treatment
- ❑
- ❑
- ❑
- ❑
- ❑

Revenues
- ❑ Waste Disposal Fees
- ❑ Fly Ash and Bottom Ash
- ❑ Recycled Product Sales
- ❑
- ❑
- ❑ Energy
- ❑ Heat
- ❑ Tipping Fees
- ❑
- ❑

Framework Organization



Geospatial Analytics using SCEnAT 4.0

SCEnAT 4.0 contains a suite of Geographic Information System (GIS), Machine Learning (ML), and Artificial Intelligence (AI) tools

Combine LCA, LCC, and spatial data
– EPA, DOE, NASA, etc.

Develop capabilities to analyze logistics in MSW system
– Identify alternate supply chains
– Enable multi-objective optimization

Instructions:
Please identify (X) which categories are most interested in/foresee the most potential in.
If something is missing, please write it in. If more space is required, or you would like to comment, please use the back of the document.
If you or your company/institution would be willing to partner with us to collect information, please circle the category

Optional
Name:________________________________
Company:______________________________
Email:________________________________

New Technologies

What alternative technology scenarios are important?

- ❑ Emissions Control
- ❑ Bottom Ash Value Recovery
- ❑ Fly Ash Value Recovery
- ❑ Sorting Methods
- ❑ Rare Earth Extraction
- ❑
- ❑

Challenging Data

What data is difficult to find, measure, or predict?

- ❑ Input waste mass, composition, and moisture content
- ❑ Effects of additives on combustion products (bottom ash, gas emissions, chemical segregation
- ❑
- ❑
- ❑
- ❑
- ❑

Environmental Outputs

What environmental information would be useful for public analysis and decision making?

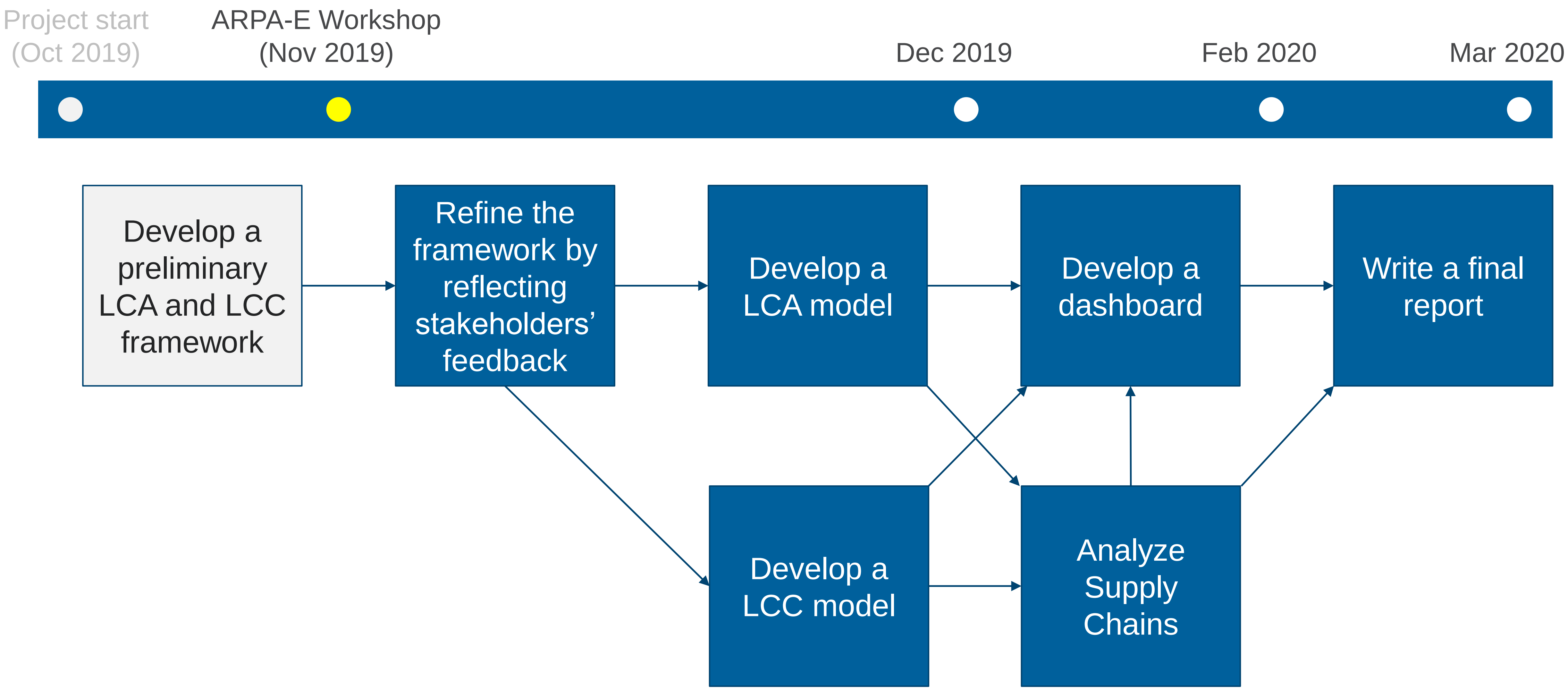
- ❑ Energy Use (total/fossil/NG/petroleum/coal/renewable)
- ❑ GHG Emissions (CO_2, CH_4, N_2O)
- ❑ Criteria Air Pollutant Emissions
- ❑ Water Consumption and Quality
- ❑ Air Ozone Depletion
- ❑ Heavy Metal Emissions (As, Pb, Hg)
- ❑ Persistent Organic Pollutant Emissions
- ❑ Recycled Mass and Composition
- ❑ Fly and Bottom Ash Mass
- ❑
- ❑
- ❑
- ❑
- ❑
- ❑
- ❑
- ❑

Valuable By/Coproducts

What value recovery opportunities are most important to further develop?

- ❑ Electricity
- ❑ Iron/Steel
- ❑ Aluminum
- ❑ Other Metals:
  ____
- ❑ HDPE/PET
- ❑ Other Plastics:
  ____
- ❑ Cement
- ❑ Fuels:
  ____
- ❑ Rare Earth Elements:
  ____
- ❑
- ❑
- ❑
- ❑
- ❑

Future work



Project start (Oct 2019)
ARPA-E Workshop (Nov 2019)
Dec 2019
Feb 2020
Mar 2020
Develop a preliminary LCA and LCC framework
Refine the framework by reflecting stakeholders' feedback
Develop a LCA model
Develop a dashboard
Write a final report
Develop a LCC model
Analyze Supply Chains

Breakdown of Unit Processes in a Combustion Facility

Questions:

What unit processes are most important?

What unit processes are missing?

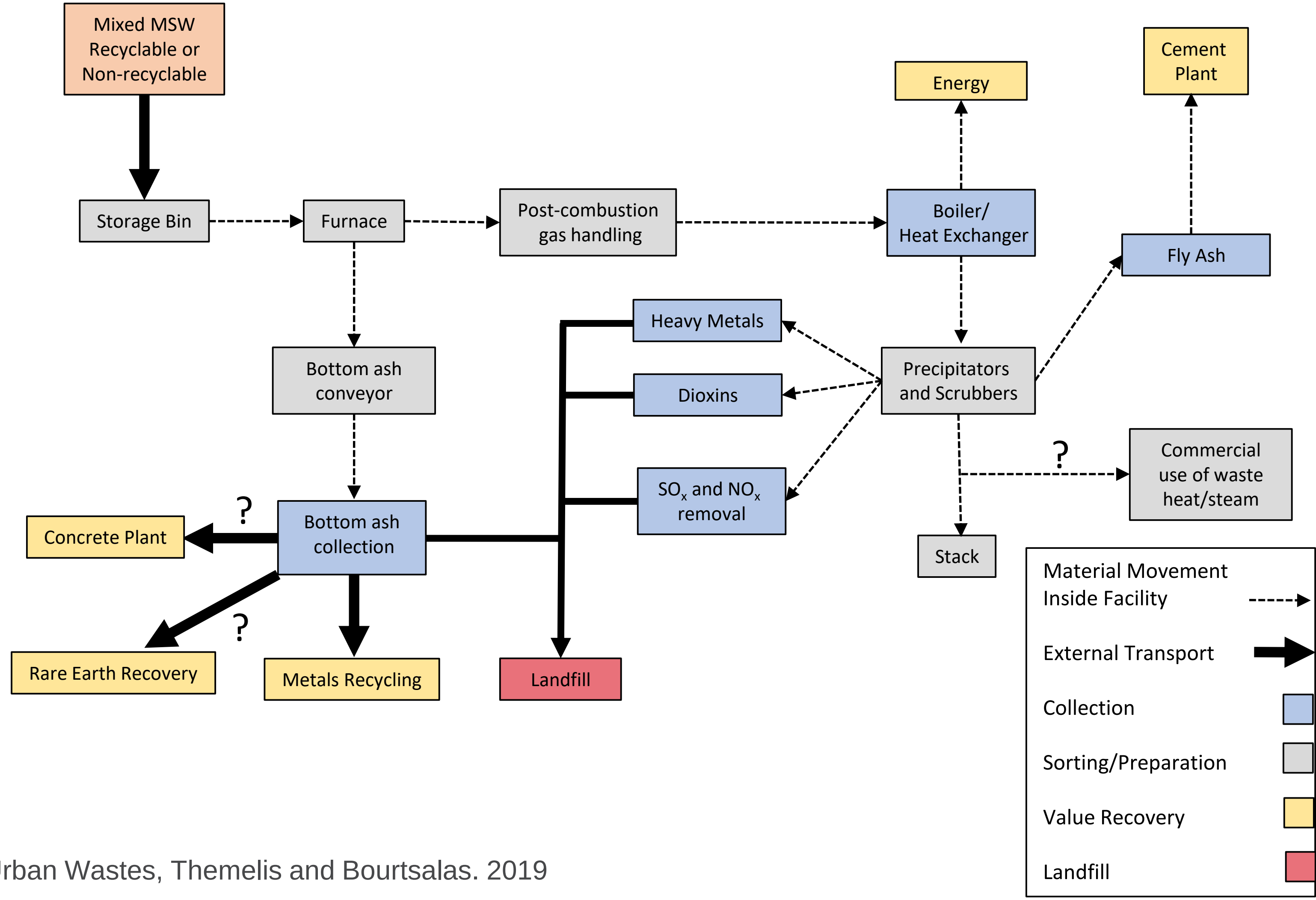
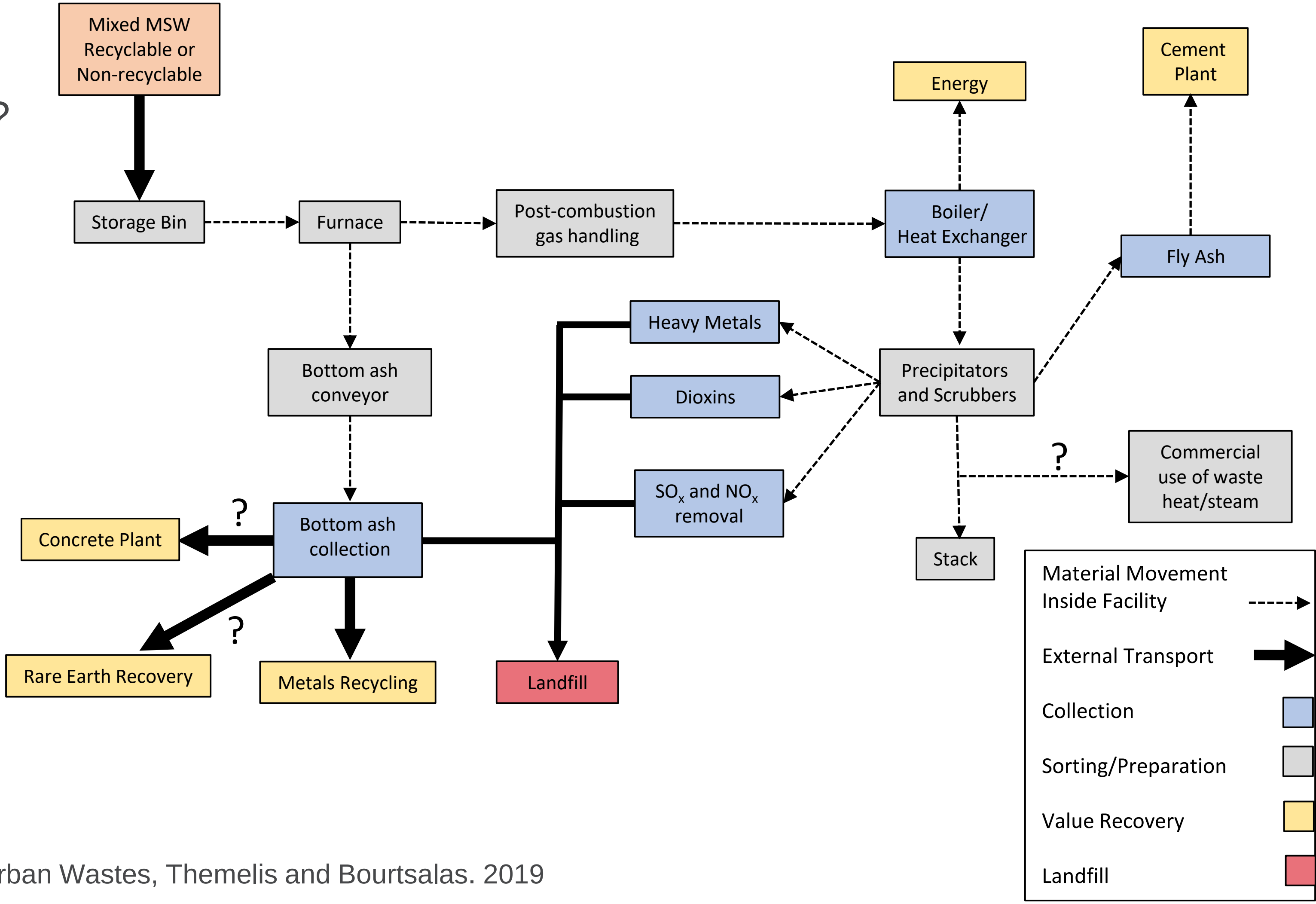


Figure adapted from Recovery of Materials and Energy from Urban Wastes, Themelis and Bourtsalas. 2019

Breakdown of Unit Processes in a Combustion Facility

Questions:

What opportunities exist for value recovery?



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